Analysis of the Electrical Grid for UAM

CIVENG 257 001 - LEC 001
Sustainable Aviation and Infrastructure
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Exploratory Study

Note to Readers

- This is an exploratory study with a top-level, first-order analysis with the following caveats
  - This study does not capture the dynamic behavior of electrical grids and users
  - This study does not capture potential future developments in electrical grids and electrical devices
  - The worst-case scenario analyzed in this study—in which metro areas can only utilize the electricity generated by power plants within their respective boundaries—does not include the electrical capacity that is available to metro areas via transmission lines
  - Therefore, the results of this study are not to be used for investment decisions

Presentation Roadmap

- Bottom Line Up Front
- Introduction
- Strategic Analyses

	Without ground EVs	With ground EVs
Analysis by electrical interconnection (grid) • Electricity can be shared between metro areas • Best case	1 599,818 UAM charging (today max)	2 475,177 UAM charging (2050 max)
Analysis by metro area* • Electricity cannot be shared between metro areas • Worst case	3 159,429 UAM charging (today max)	4 94,541 UAM charging (2050 max)

*40 largest metro areas by population

\# = Order of presentation

- Bottom Line and Recommendations

Bottom Line Up Front

- Many technology, infrastructure, regulatory, and acceptance challenges to conduct UAM operations with eVTOLs profitably at scale while also meeting demand
  - Morgan Stanley's recent projection of the UAM Total Addressable Market worldwide through 2040 is 1/3 smaller than their 2018 projection due to these challenges

- Success of UAM depends upon the availability of electricity

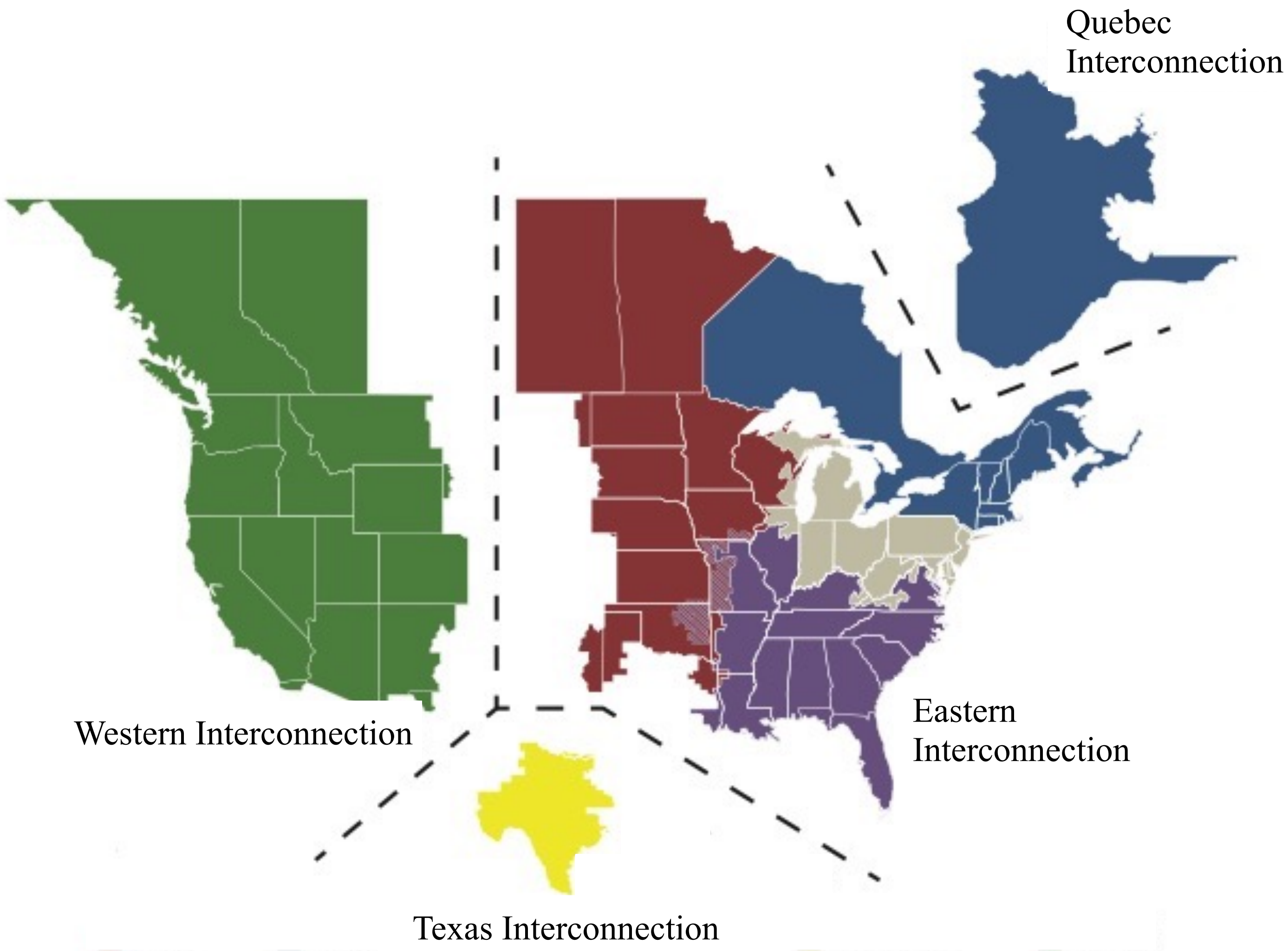
No electricity → No powered flight → No business case

  - UAM eVTOLs may not be able to charge at scale large enough for business case
    - Lack of available electrical grid capacity may constrain UAM operations below UML-5 in many U.S. metro areas before 2050
    - Ground EVs will proliferate and consume more and more electrical grid capacity over time

Available electrical grid capacity may be a formidable constraint for UAM, in addition to regulatory/policy hurdles and public support

Introduction

Electrical Grids (aka Interconnections) in North America



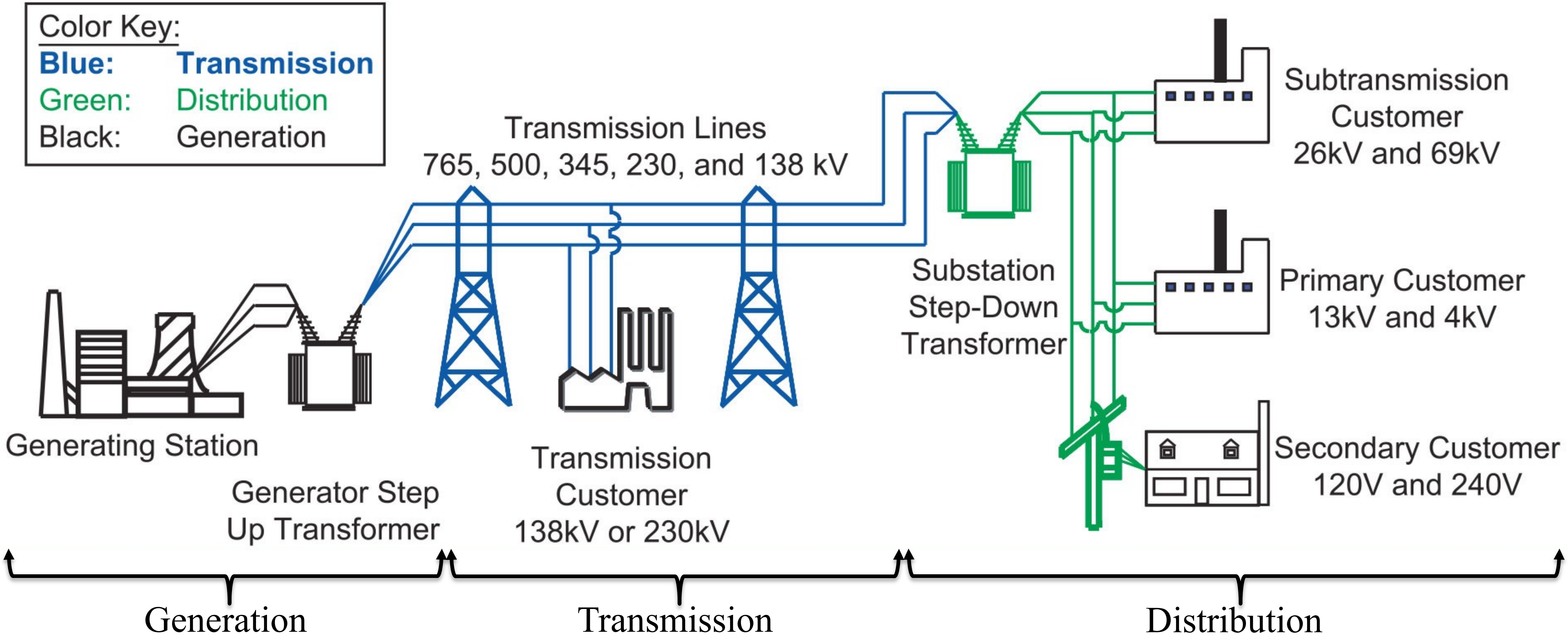
The U.S. is part of three major electrical grids

- Western Interconnection
- Eastern Interconnection
- ERCOT (Electricity Reliability Council of Texas) Interconnection

Today's analysis is for the continental U.S. (does not include Alaska, Hawaii, or Canada)

Source: North American Electricity Reliability Corporation (NERC)
https://www.nerc.com/AboutNERC/keyplayers/PublishingImages/NERC%20Interconnections.pdf

Electrical Grid Structure



Interconnections can share some regional generation and transmission capacity, but not local distribution capacity

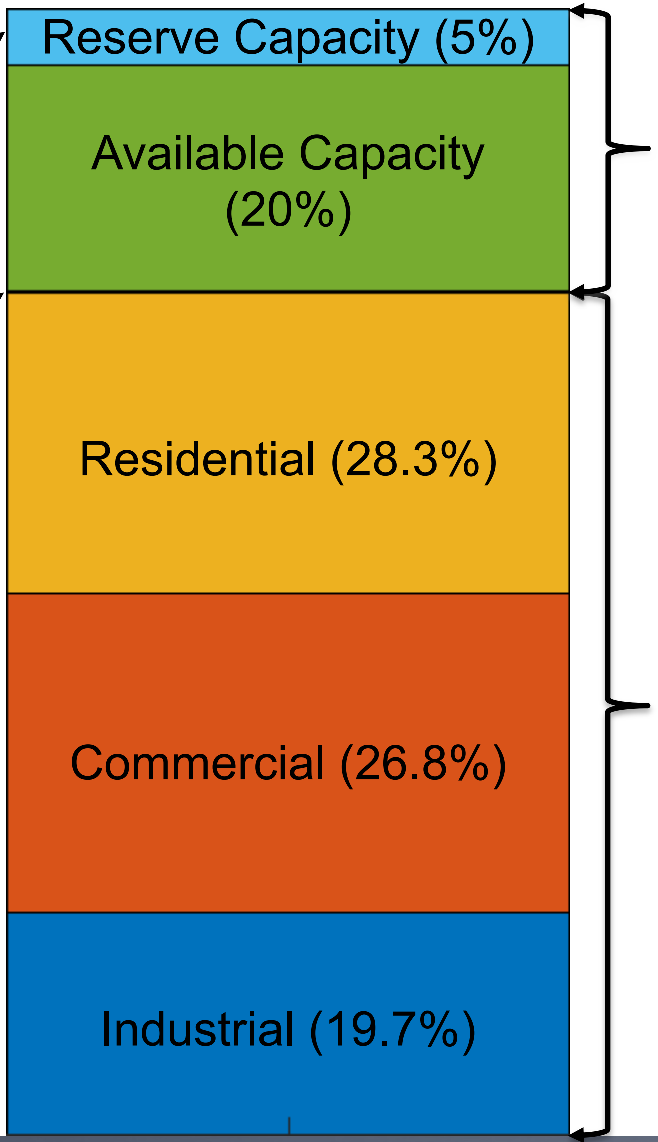
Source: https://www.nps.gov/subjects/renewableenergy/transmission.htm

U.S. Electrical Grid Utilization (2019)

- Assume for maintenance, contingencies, etc.
- Based on historical high electrical grid utilization of ~95% (~1970 and 2000)

Transportation (0.15%)
- Expected to grow to 11.9% by the year 2050
- Projection only includes ground transportation

- Peak ground EV electricity usage occurs in early evening
- UAM trips and charging also expected to have a peak during this time



2019 unutilized capacity: 25%

This analysis is on the sufficiency of available electrical grid capacity for UAM

2019 utilized capacity: 75%

Source (electrical grid utilization): Federal Reserve Bank of St. Louis https://fred.stlouisfed.org/series/CAPUTLG2211S#0

Source (electricity usage): U.S. Energy Information Administration https://www.eia.gov/electricity/annual/html/epa_02_02.html

Source (electricity usage projection): National Renewable Energy Laboratory: https://www.nrel.gov/docs/fy18osti/71500.pdf https://data.nrel.gov/submissions/90

Source (peak ground EV electricity usage): https://www.energy.gov/sites/prod/files/2019/12/f69/GITT%20ISATT%20EVs%20at%20Scale%20Grid%20Summary%20Report%20FINAL%20Nov2019.pdf

Variables Modeled and their Ranges

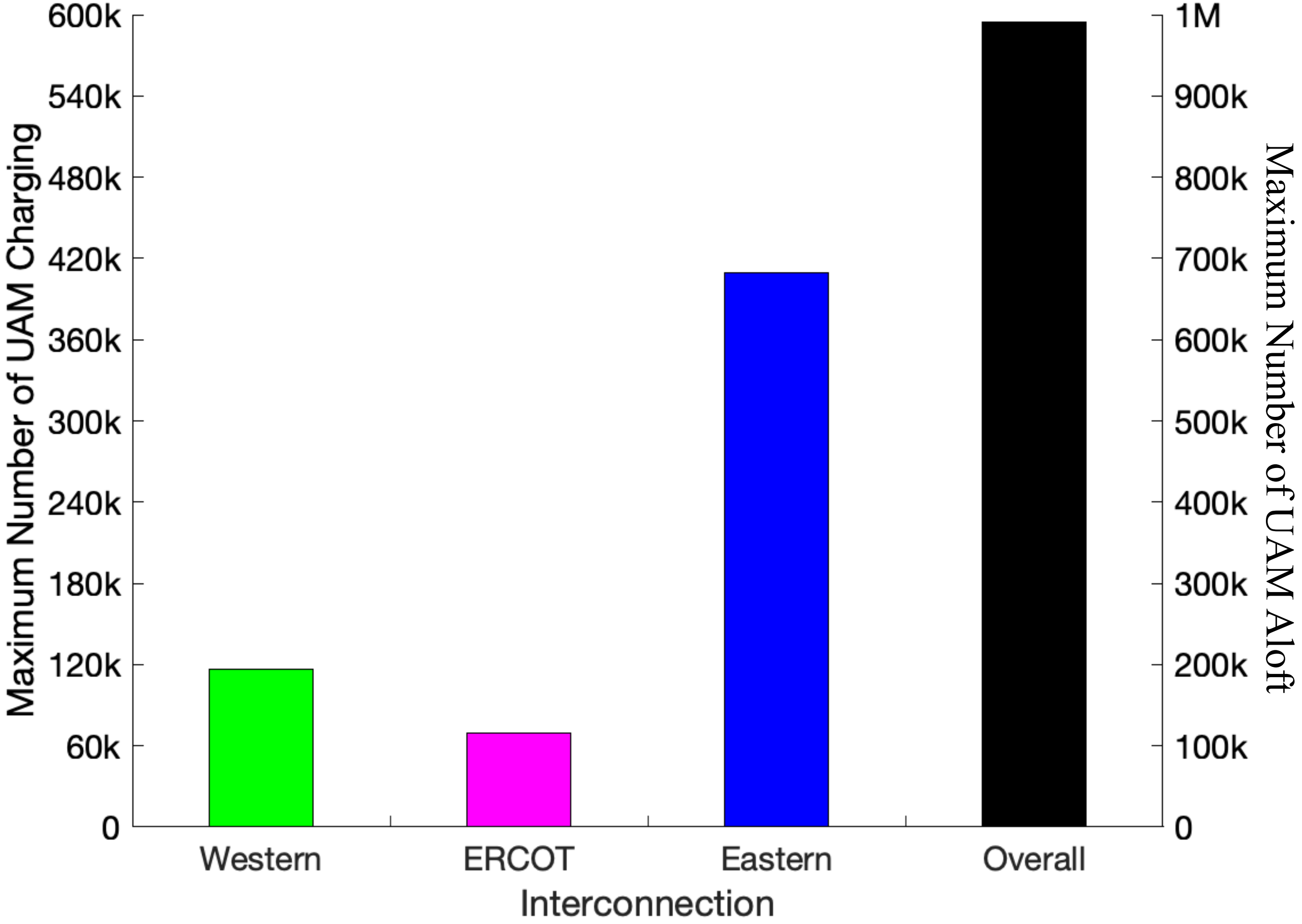
Variable	Baseline Value	Range of Values in Sensitivity Analysis	Data Source(s)
Available electrical grid capacity	20%	0%-50%	Federal Reserve Bank of St. Louis; eia U.S. Energy Information Administration
Electricity generation capacity growth rate	1.54% (per annum; base scenario)	1.25%-2%	eia U.S. Energy Information Administration
Population growth rate	0.52% (per annum; main series)	0.35%-0.75%	United States Census Bureau
Ground EV ownership	40% (low among cluster of estimates)	5-50%	U.S. Department of Energy; Bloomberg New Energy Finance; IHS Markit
Ground EV charging power	7.2 kW (common Level-2 charging)	4.8-9.6 kW	U.S. Department of Energy
Ground EV peak charging	20%	5-25%	U.S. Department of Energy; USDRIVE
UAM charging power	400 kW; RVLT quadrotor eVTOL; 7-min recharge after 20-nmi flight at 130 kts	200 kW-600 kW	Black & Veatch 

Values from industry and government sources
Conducted sensitivity analysis on each variable

Analysis by Electrical Interconnection (Grid)

	Without ground EVs	With ground EVs
Analysis by electrical interconnection (grid) • Electricity <u>can</u> be shared between metro areas • Best case	1 599,818 UAM charging (today max)	2 475,177 UAM charging (2050 max)
Analysis by metro area (top 15; extending to top 40) • Electricity <u>cannot</u> be shared between metro areas • Worst case	3 159,429 UAM charging (today max)	4 94,541 UAM charging (2050 max)

Estimated Maximum Number of UAM Operations Possible—Today



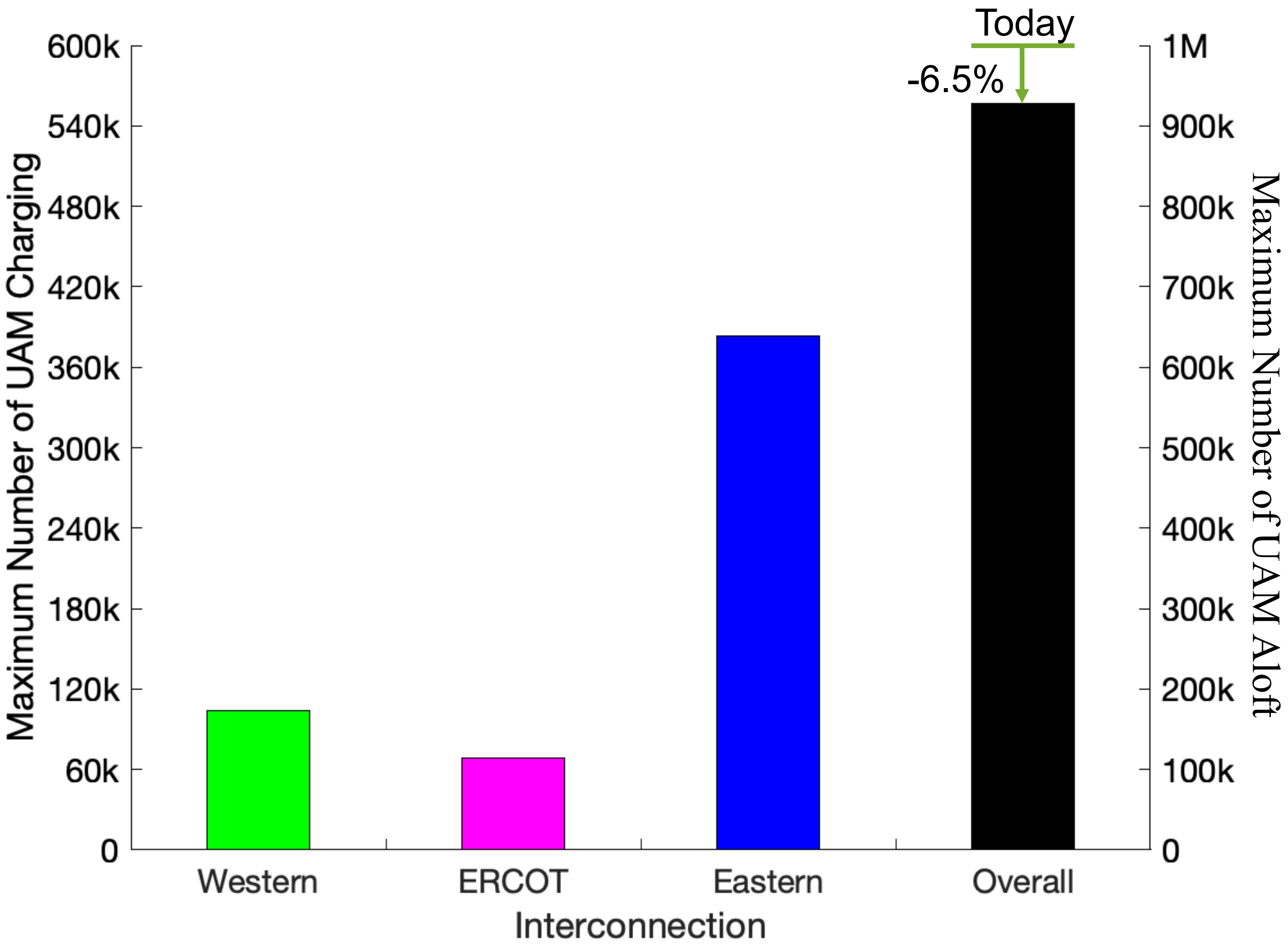
- The analysis here only has a <u>ground EV fleet of 0.5%</u>

- The impact of ground EVs on the maximum number of UAM operations possible today is small

- Of all the UAM in an interconnection
  - 50% are aloft
  - 30% are recharging at vertiport
  - 20% are parked at vertiport

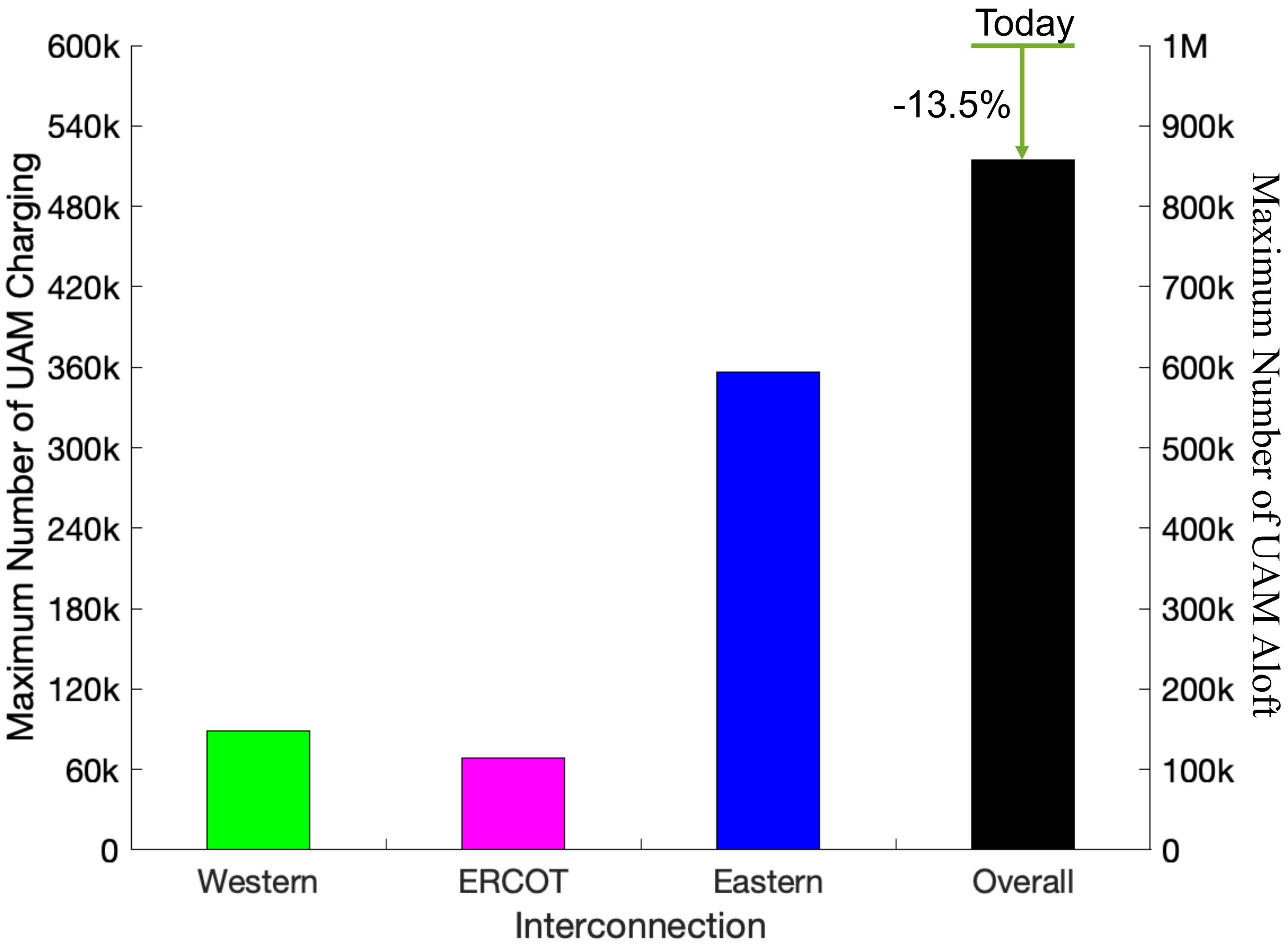
- For example, in the CONUS today, there is available electrical grid capacity for 600k UAM to be charging simultaneously and 1M UAM to be aloft at the same time

Estimated Maximum Number of UAM Operations Possible—2030



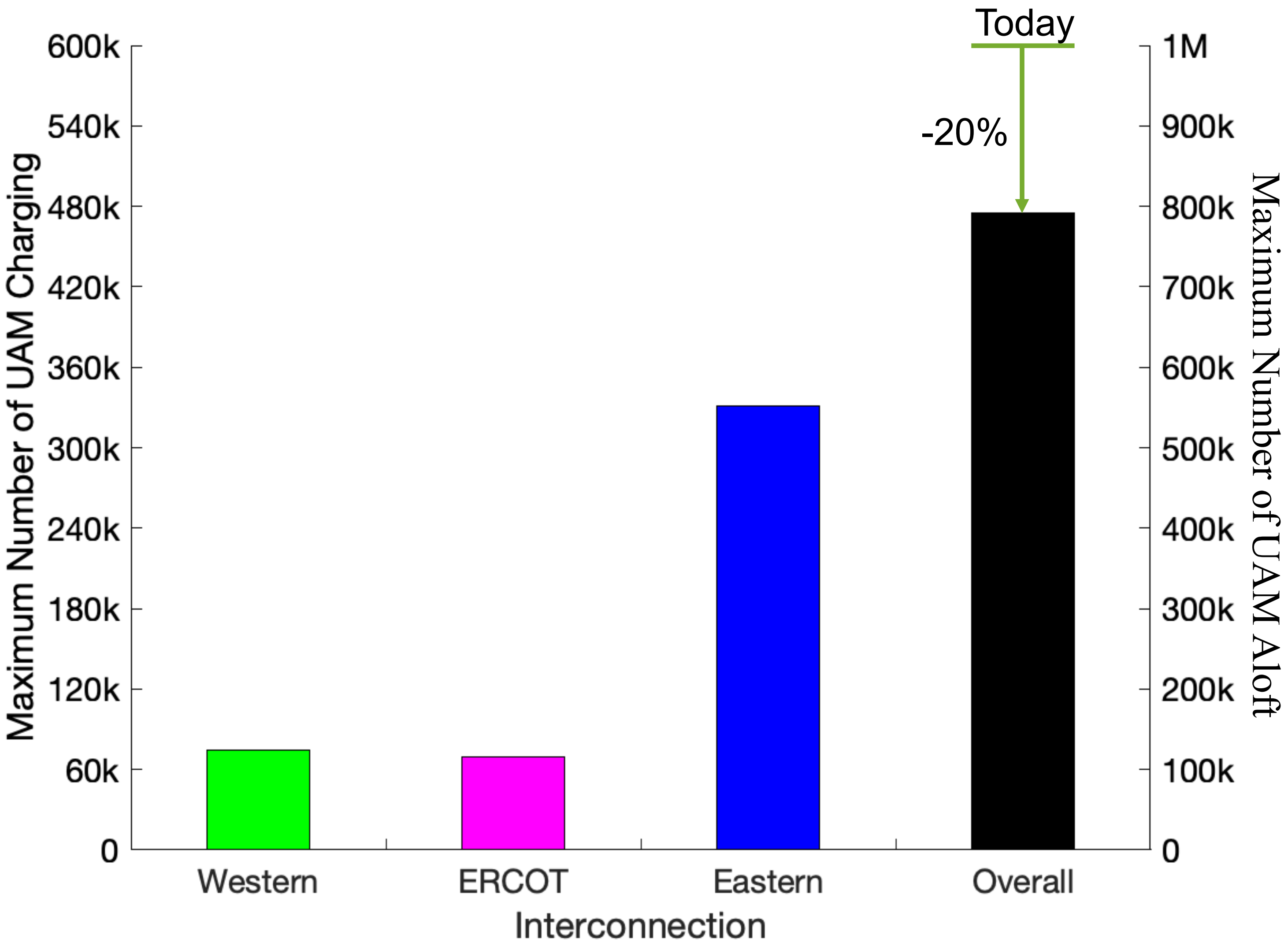
- The analysis here has a ground EV fleet of 12.8%
- Proliferation of ground EVs will consume more of the available electrical grid capacity

Estimated Maximum Number of UAM Operations Possible—2040



- The analysis here has a ground EV fleet of 26.4%
- Proliferation of ground EVs will consume even more of the available electrical grid capacity

Estimated Maximum Number of UAM Operations Possible—2050



- The analysis here has a <u>ground EV fleet of 40%</u>
- Proliferation of ground EVs is estimated to reduce the maximum number of UAM operations possible in 2050 by 20%
- This is a best-case scenario in which electricity <u>can</u> be transmitted and distributed within each interconnection as needed
- This may require as much as
  - $1.7T investments to remove power distribution constraints
  - $0.7T to increase transmission capacity

Analysis by Metro Area

	Without ground EVs	With ground EVs
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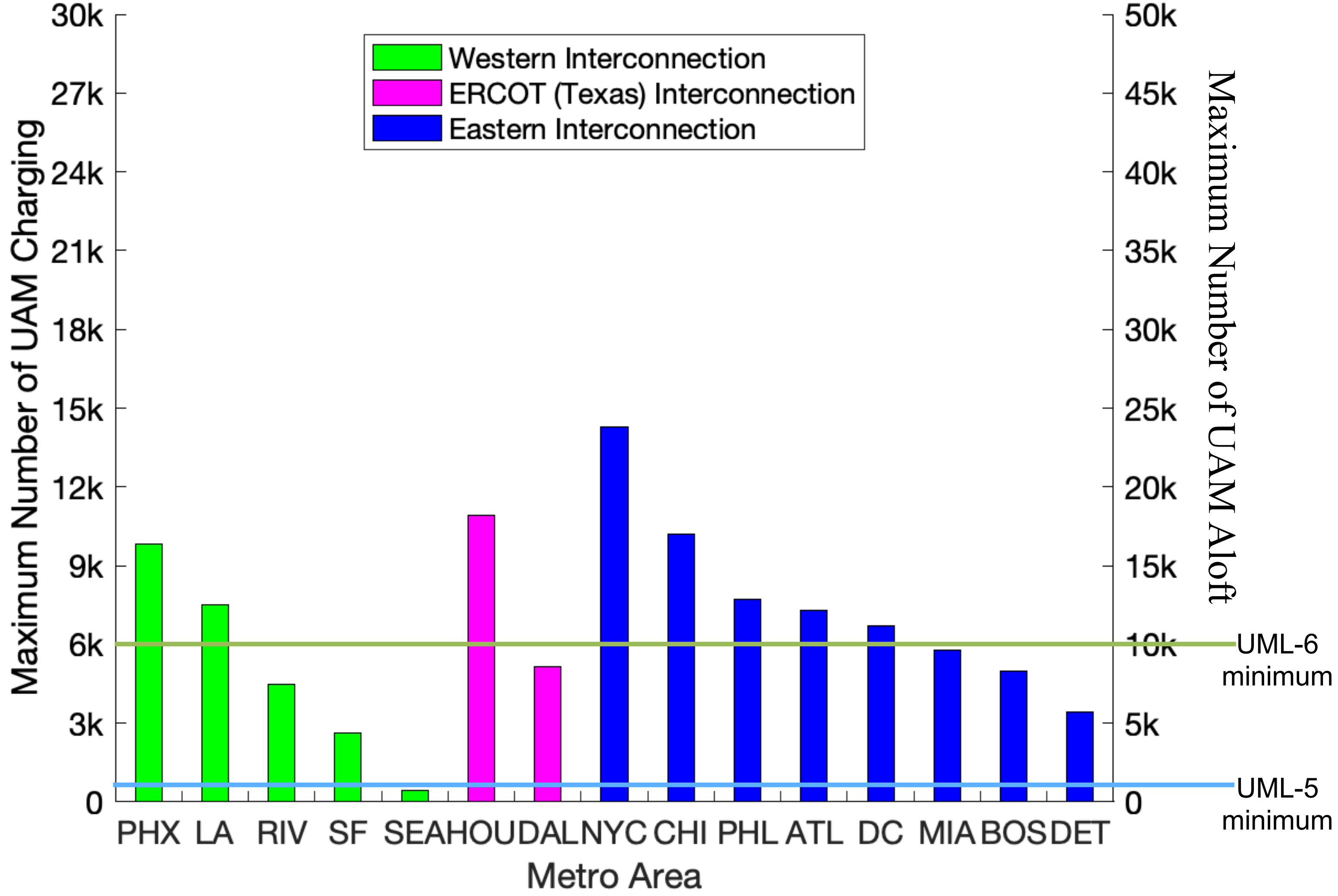
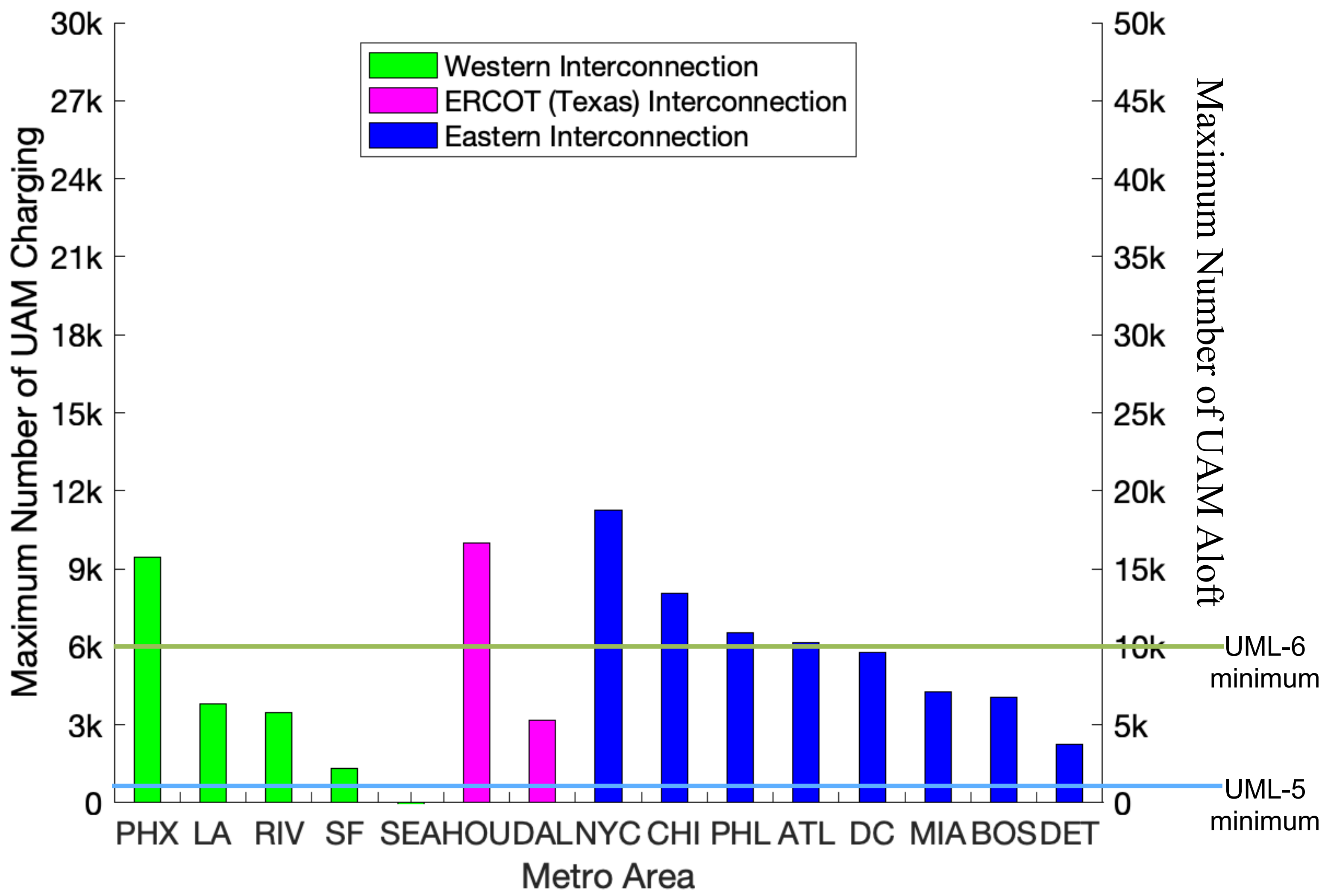
Estimated Maximum Number of UAM Operations Possible—Today



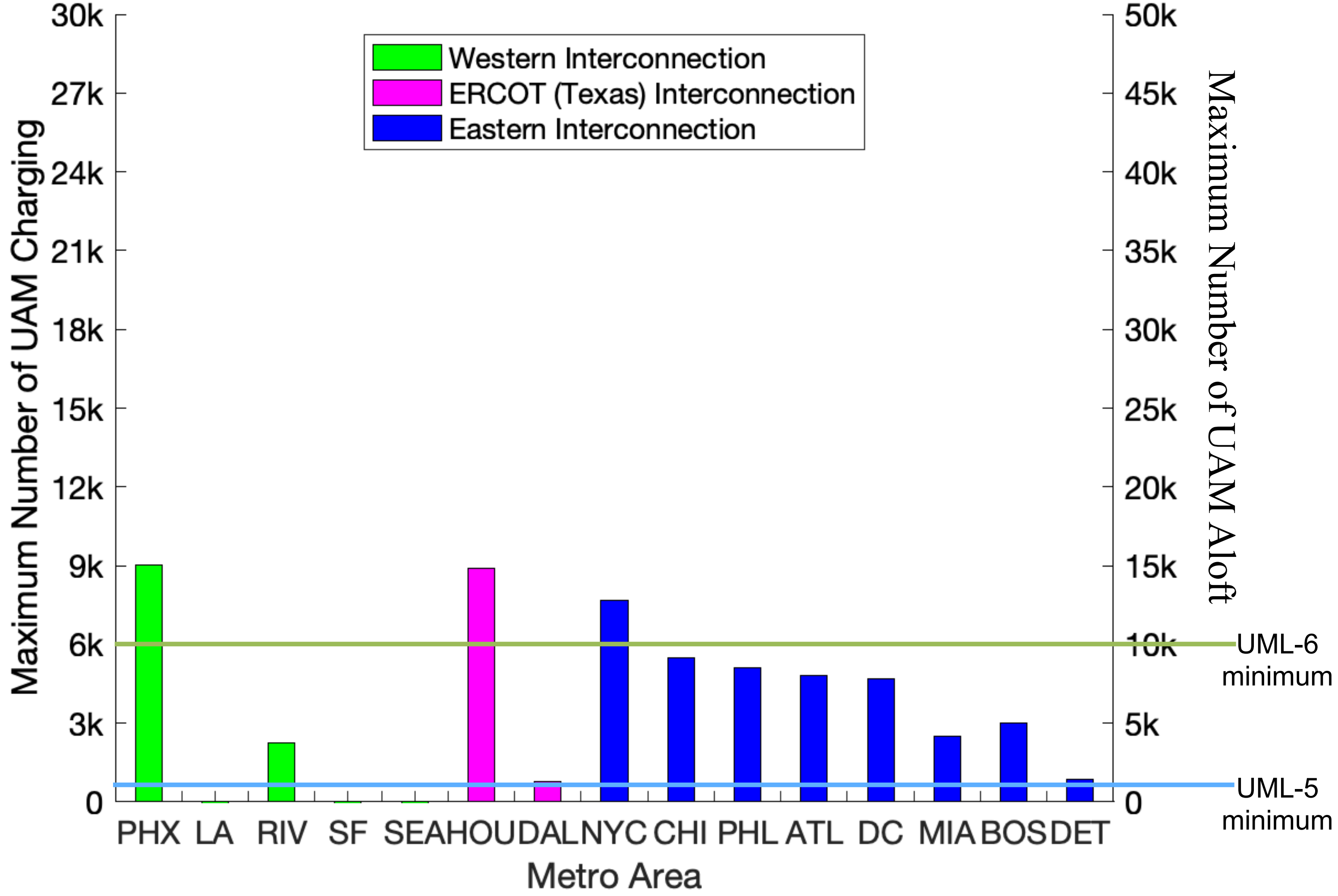
- The analysis here only has a <u>ground EV fleet of 0.5%</u>
- The impact of ground EVs on the maximum number of UAM operations possible today is small
- There may only be available electrical grid capacity for UML-6 operations in eight U.S. metro areas today <u>**if**</u> electricity cannot be transmitted and distributed within each interconnection as needed

Estimated Maximum Number of UAM Operations Possible—2030



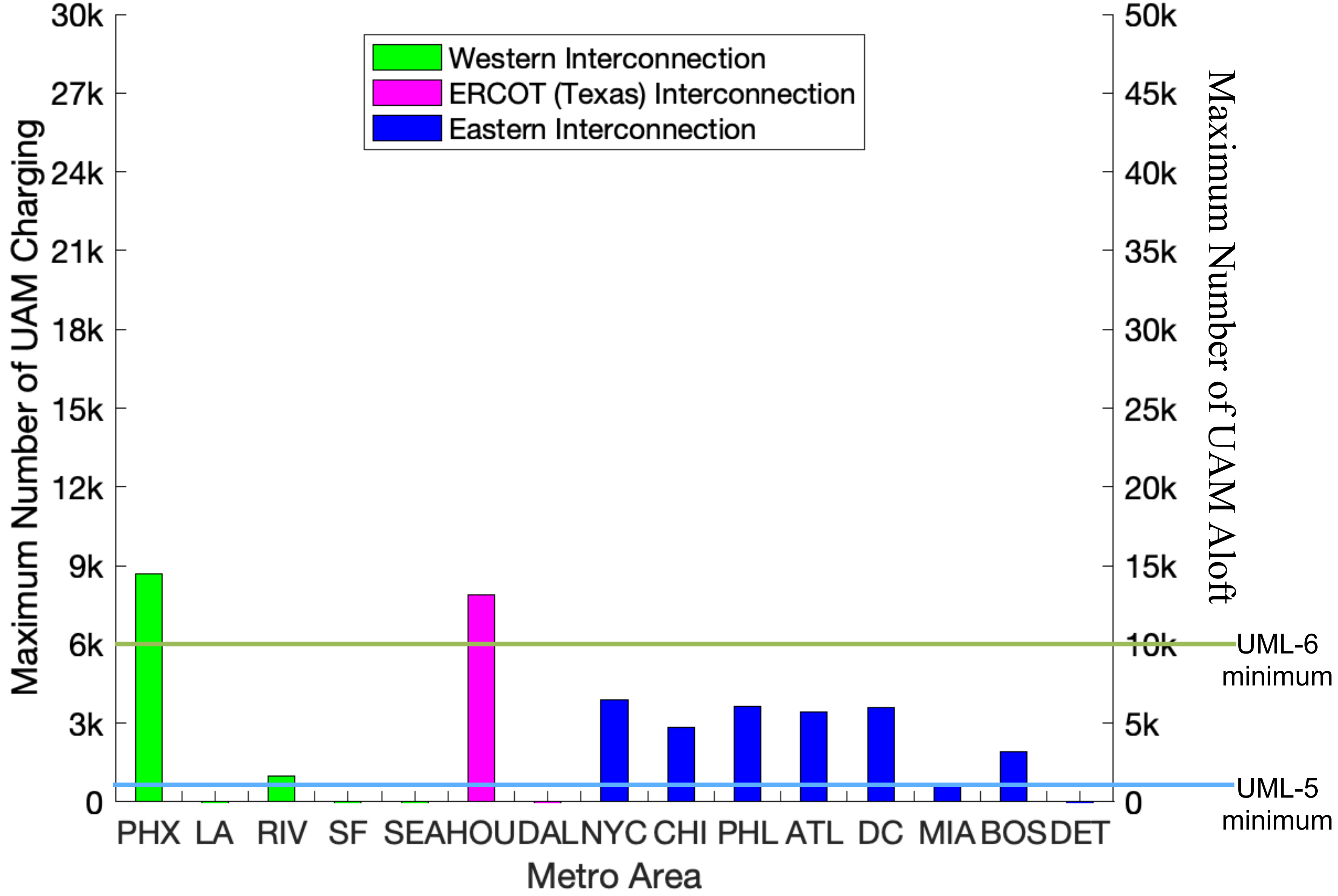
- The analysis here has a <u>ground EV fleet of 12.8%</u>
- Proliferation of ground EVs will consume more of the available electrical grid capacity
- Due to lack of power, additional metro areas may no longer be able to conduct UML-6 operations
- Some metro areas may not have available electrical grid capacity to conduct any UAM operations

Estimated Maximum Number of UAM Operations Possible—2040



- The analysis here has a ground EV fleet of 26.4%
- Proliferation of ground EVs will consume even more of the available electrical grid capacity
- Due to lack of power, most metro areas may not be able to conduct UML-6 operations
- Additional metro areas may not have available electrical grid capacity to conduct any UAM operations

Estimated Maximum Number of UAM Operations Possible—2050



- The analysis here has a ground EV fleet of 40%
- Proliferation of ground EVs will consume even more of the available electrical grid capacity
- Due to lack of power, nearly all metro areas may not be able to conduct UML-6 operations
- Even more metro areas may not be able to conduct any UAM operations
- This is a worst-case scenario in which electricity cannot be transmitted and distributed within each interconnection as needed

Trends Suggested from Sensitivity Analyses

Variable (in order from most sensitive to least)	Why the Maximum # of UAM Operations Possible may be Lower than Estimated in the Analyses	Areas/Sources of Variation
Available electrical grid capacity	Available power can be lower than national average of 20% (e.g., during periods of high demand, if electrification in general is broader and/or faster than expected)	Interconnections, metro areas, seasons, time of day, extreme weather conditions and events
UAM charging power	UAM aircraft and operations may require charging faster than the nominal 400 kW value used in this analysis	UAM vehicle type, missions, operating/environmental conditions
Ground EV peak charging	More ground EVs may need to charge to a greater extent during less-than-ideal conditions	Seasons, time of day
Ground EV ownership	Ground EV prices decrease faster than expected	Interconnections, metro areas
Ground EV charging power	Some current ground EVs and additional future ground EVs are capable of charging faster than the nominal 7.2 kW value used in this analysis	Ground EV makes and models
Electricity generation capacity growth rate	Cost of renewable electricity generation technologies decrease less than expected, overall economic growth is lower than expected	Renewable generation technology costs, economic growth
Population growth rate	Greater than expected population growth can increase the number and impact of ground EVs	Fertility, mortality, migration rates

Bottom Line and Recommendations

Bottom Line

- Many technology, infrastructure, regulatory, and acceptance challenges to conduct UAM operations with eVTOLs profitably at scale while also meeting demand

- Success of UAM depends upon the availability of electricity

No electricity → No powered flight → No business case

- UAM eVTOLs may not be able to charge at scale large enough for business case
  - Lack of available electrical grid capacity may constrain UAM operations below UML-5 in many U.S. metro areas before 2050
  - Ground EVs will proliferate and consume more and more electrical grid capacity over time

Available electrical grid capacity may be a formidable constraint for UAM, in addition to regulatory/policy hurdles and public support

Recommendations

- Develop comprehensive estimates of UAM energy needs under expected range of
  - Missions (e.g., speed, distance, load)
  - Operating conditions (e.g., wind)
  - Requirements (e.g., maximum charging/turnaround time)

- Reduce or eliminate the need to recharge during early evening peak, such as by
  - Reducing structural mass
  - Increasing battery energy density

- Incorporate UAM requirements into metro area and utility company plans at least several years in advance (if additional infrastructure is needed)